Methodology for Development of Drought Severity-Duration-Frequency (SDF) Curves

A thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

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DECLARATION

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

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ABSTRACT

Drought monitoring and early warning are essential elements impacting drought sensitive sectors such as primary production, industrial and consumptive water users. A quantitative estimate of the probability of occurrence and the anticipated severity of drought is crucial for the development of mitigating strategies. The overall aim of this study is to develop a methodology to assess drought frequency and severity and to advance the understanding of monitoring and predicting droughts in the future. Seventy (70) meteorological stations across Victoria, Australia were selected for analysis. To achieve the above objective, the analysis was initially carried out to select the most applicable meteorological drought index for Victoria. This is important because to date, no drought indices are applied across Australia by any Commonwealth agency quantifying drought impacts. An evaluation of existing meteorological drought indices namely, the Standardised Precipitation Index (SPI), the Reconnaissance Drought Index (RDI) and Deciles was first conducted to assess their suitability for the determination of drought conditions. The use of the Standardised Precipitation Index (SPI) was shown to be satisfactory for assessing and monitoring meteorological droughts in Australia. When applied to data, SPI was also successful in detecting the onset and the end of historical droughts.

Temporal changes in historic rainfall variability and the trend of SPI were investigated using non-parametric trend techniques to detect wet and dry periods across Victoria, Australia. The first part of the analysis was carried out to determine annual rainfall trends using Mann Kendall (*MK*) and Sen's slope tests at five selected meteorological stations with long historical records (more than 100 years), as well as a short sub-set period (1949-2011) of the same data set. It was found that different trend results were obtained for the sub-set. For SPI trend analysis, it was observed that, although different results were obtained showing significant trends, SPI gave a trend direction similar to annual precipitation (downward and upward trends). In addition, temporal trends in the rate of occurrence of drought events (i.e. inter-arrival times) were examined. The fact that most of the stations showed negative slopes indicated that the intervals between events were becoming shorter and the frequency of events was temporally increasing. Based on the results obtained from the preliminary analysis, the trend analyses were then carried out for the remaining 65 stations. The main conclusions from these analyses are summarized as follows; 1) the trend analysis was observed to be highly dependent on the start and end dates of analysis. It is recommended that in the selection of time period for the drought, trend analysis should consider the length

of available data sets. Longer data series would give more meaningful results, thus improving the understanding of droughts impacted by climate change. 2) From the SPI and inter-arrival drought trends, it was observed that some of the study areas in Victoria will face more frequent dry period leading to increased drought occurrence. Information similar to this would be very important to develop suitable strategies to mitigate the impacts of future droughts.

The main objective of this study was the development of a methodology to assess drought risk for each region based on a frequency analysis of the drought severity series using the SPI index calculated over a 12-month duration. A novel concept centric on drought severity-duration-frequency (SDF) curves was successfully derived for all the 70 stations using an innovative threshold approach. The methodology derived using extreme value analysis will assist in the characterization of droughts and provide useful information to policy makers and agencies developing drought response plans. Using regionalisation techniques such as Cluster analysis and modified Andrews curve, the study area was separated into homogenous groups based on rainfall characteristics. In the current Victorian application the study area was separated into six homogeneous clusters with unique signatures. A set of mean SDF curves was developed for each cluster to identify the frequency and severity of the risk of drought events for various return periods in each cluster. The advantage of developing a mean SDF curve (as a signature) for each cluster is that it assists the understanding of drought conditions for an ungauged or unknown station, the characteristics of which fit existing cluster groups. Non-homogeneous Markov Chain modelling was used to estimate the probability of different drought severity classes and drought severity class predictions 1, 2 and 3 months ahead. The non-homogeneous formulation, which considers the seasonality of precipitation, is useful for understanding the evolution of drought events and for short-term planning. Overall, this model predicted drought situations 1 month ahead well. However, predictions 2 and 3 months ahead should be used with caution.

Many parts of Australia including Victoria have experienced their worst droughts on record over the last decade. With the threat of climate change potentially further exacerbating droughts in the years ahead, a clear understanding of the impact of droughts is vital. The information on the probability of occurrence and the anticipated severity of drought will be helpful for water resources managers, infrastructure planners and government policy-makers with future infrastructure planning and with the design and building of more resilient communities.

CHAPTER 1

INTRODUCTION

1.1 Background

Droughts occur over most parts of the world, in both dry and humid regions and affect human welfare and food security. In south-eastern Australia (Victoria, parts of New South Wales and South Australia), several major droughts have occurred in the past, including the Federation drought (1895 - 1903), the World War II drought (1937 - 1945), and in 1963-1968, 1982-1983 and from 1991-1995. In recent years (from 1997 to 2009), most of Australia suffered from precipitation deficit-driven drought over an extended period, which adversely impacted living standards, primary production, economic prosperity and environmental health (Ummenhofer *et al.*, 2009). The twelve-year prolonged dry period included four major drought years covering 1997, 2002, 2006 and 2008. As a result, many aspects of drought have received much attention over the last decade in Australia.

Drought is referred to as a creeping phenomenon, as its effects often take time (weeks or months) to impact. This makes it challenging to determine when a drought begins and likewise, when a drought is over. Owing to the frequent occurrence of drought and its slowly developing nature, the development of a comprehensive drought monitoring system that can provide early warning of drought onset and its end should be given more attention. With such information, the economic, social and environment impacts of drought could be reduced. Drought indices are often used for detecting the early onset and end of droughts. Several drought indices have been used effectively as drought assessment tools in other parts of the world (Hayes *et al.*, 1999; Tsakiris *et al.*, 2007; Asadi Zarch *et al.*, 2011; Barua *et al.*, 2011). In Australia, the Bureau of Methodology (BoM) uses Deciles to assess the status of rainfall deficiency throughout Australia. Formal drought declarations and assistance are handled by state and Commonwealth governments. In Victoria for example, the Department of Environment and Primary Industries is responsible for the provision of information related to drought. The Commonwealth government is responsible for national policy and implementing national drought relief initiatives such as drought relief packages. Therefore, the Commonwealth and the states would greatly benefit from the development of an appropriate drought assessment tool that could apply consistently across jurisdictions.

Drought forecasting is an important aspect of drought hydrology and it plays a major role in risk management, drought preparedness and the implemention of mitigation measures. Extensive work has been done on modelling various aspects of drought, such as the identification and prediction of its duration and severity. However, a major research challenge still remains, primarily requiring the application of suitable techniques for forecasting the onset and termination points of droughts, especially in Australia.

1.2 Research Questions

As vulnerability to drought has increased globally, greater attention has been directed to reducing the risks associated with its occurrence. The present study therefore seeks to answer the following questions:

- What is the most applicable meteorological drought index for Victoria?
- Are there any trends in the climatic data and inter-arrival times of droughts?
- Can drought forecasting tools provide information (severity, probability, duration) on future droughts?
- What is the probability of the occurrence of droughts?

1.3 Aims of the study

The main aim of this research project is to develop a methodology to assess drought frequency and severity and to forecast droughts in the future. The aim of the study was achieved by primarily undertaking the following tasks:

1) Reviewing drought indices
2) Selecting the most applicable meteorological drought index for Victoria.
3) Analysing rainfall and drought severity trends for selected locations.
4) Developing the drought severity-duration-frequency (SDF) curves for various return periods over the region.

5) Identifying homogeneous regions with similar drought characteristics.
6) Developing SDF curves for each homogenous region.
7) Forecasting future drought conditions using drought forecasting tools for short durations (less than or equal to 3 months).

1.4 Research significance

In this section, the significance of the research and the possible outcomes are discussed. These contributions are outlined below:

- As was mentioned in Section 1.1, to date, there have been no drought indices applied across Australia by any Commonwealth agency except the Bureau of Methodology (BoM), which uses Deciles to assess the status of rainfall deficiency throughout Australia. In Australia, state-based agencies are responsible for operational decision-making. They use independently-derived indices to assist operational planning. As there is no consistency between regions and states, comparison either within a state or between states in a region is difficult. Therefore, there is a need to select the most appropriate drought index and apply it consistently throughout Australia to provide essential information on droughts (e.g. lead time, duration, magnitude (or severity), the onset and end of drought, etc.) which would help state-based organisations and the Commonwealth to plan and implement responses and mitigation measures.
- Trend analysis will facilitate the identification of any possible trends in climatic parameters which directly influence the occurrence of drought. To date, no comprehensive research has been conducted on drought severity trends in the country. Hence, whether there is a possible trend in the risk of occurrence of drought events will be determined.
- Drought information is often too technical and difficult to understand by decision-makers and end-users. This study aims to initially derive information about drought and its recurrence using precipitation information which can be understood easily by ordinary users.
- Regionalization methods for catchment groupings will identify homogenous areas with respect to drought. That is, stations that depict similar drought characteristics will be identified. This will reduce the heterogeneity of the study area so that the

methodology developed can be used with greater confidence to predict vulnerability to drought at any location within a particular region. Regionalization methods have been used for the classification and comparison of different aspects of yield hydrology, but not for drought characterisation. This study aims to explore regionalisation techniques for droughts.

- The drought-forecasting model will also be applied in this study and it is a useful tool which can become part of an early warning system to provide early indication of future drought conditions. Short-term prediction of the drought severity for the following one, two and three months could be achieved.

1.5 Outline of the Thesis

Chapter 1 describes the background of the research, the aims and the research significance. It also formulates the research questions to be addressed and provides an overall picture of the research tasks undertaken in the thesis.

Chapter 2 presents a comprehensive critical review of research related to drought indices and drought forecasting techniques and history of Australian droughts. This chapter identifies the current state of knowledge and research gaps in drought management.

Chapter 3 provides a description of the study area, the climatic data used and relevant information on the selected rainfall stations. The procedures of gap filling of monthly rainfall data are also given. This chapter also presents results of preliminary analysis on the assessment of droughts using meteorological drought indices (i.e. Standardised Precipitation Index (SPI), Reconnaissance Drought Index (RDI) and Theory of Runs (ToR)) that paved the way for the subsequent analyses. The work presented here has been published in *Journal of Hydrological Reasearch*.

Chapter 4 investigates the trend by non-parametric tests and a change point analyses (to detect point of change) of rainfall data for shorter and longer data lengths. This chapter also examines the spatial and temporal distributions of identified trends. The work presented here has been published in *Journal of Water and Climate Change*. Similar to the above analysis, this chapter provides the trend of wet/dry periods using selected meteorological drought index, namely the SPI and the temporal trends in drought events.

Development of the drought severity-duration-frequency (SDF) curves is presented in Chapter 5. This chapter also applies multivariate statistical techniques to identify homogeneous regions based on climatic characteristics which are related to the selected drought index. An independent validation of the SDF curves is also pesented.

Chapter 6 presents the use of Markov Chain modelling in order to estimate the probability of different drought severity classes and drought severity class predictions at one, two and three months ahead. Predictions of drought are also tested for historical drought events in Victoria and reported in this chapter.

Finally, Chapter 7 presents a summary and the main conclusions drawn from individual research components. Recommendations for future work are also presented.

Chapter 1 Introduction

- Background of the research, the aims and research significance

Chapter 2 Literature Review

- Review on drought indices, trend analysis, spatio - temporal drought analysis, regionalisation techniques and drought forecasting techniques to identify the gaps and design the research objectives and the scope of the study

Chapter 3 Description of Study Area and Preliminary Analysis of Climatic Data

- Selection of study area and climatic data
- Assessing three selected meteorological drought indices

Chapter 4 Trend Analysis of Rainfall and Standardised Precipitation Index (SPI)

- Trend analysis of annual rainfall and identifying the change point of the trend
- Trend of SPI
- Inter-arrival times of drought trend

Chapter 5 Development of Drought Severity-Duration-Frequency (SDF) Curves

- Development of severity-duration-frequency (SDF)
- Application of regionalisation techniques

Chapter 6 Forecast Future Drought Condition using Markov Chains Model

- Non-homogeneous formulation
- Drought class probabilities and short term drought class predictions

Chapter 7 Summary, Conclusions and Recommendations

- Summary and conclusions
- Limitations of the study and recommendations for future research

Figure 1.1 Outline of the thesis

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the definition of drought and its classification. These aspects of droughts have been widely discussed in the literature and remain major research topics. Some findings that have been reported from other studies are also reviewed and discussed. Precipitation, temperature, wind and relative humidity are important factors to include in characterizing drought. Since these climatic parameters vary temporally and spatially, there is a need to consider these meteorological aspects to assess drought frequency and severity, and to forecast droughts in the future.

Drought means different things to different people, depending on their choice of the form of water and its related aspects of interest. Hence, it is important to characterise drought into meteorological, hydrological, agricultural and socio-economic droughts (Beran and Rodier, 1985; Wilhite and Glantz, 1985; Nalbantis and Tsakiris, 2009). Meteorological drought is commonly defined as lack of precipitation over a region over a period of time. The consequential impacts of a meteorological drought over time lead to other drought categories, i.e. agricultural, hydrological or socio-economic droughts (Dracup *et al.*, 1980; Khalili *et al.*, 2011), as shown in Figure 2.1. Many studies involving precipitation have been carried out for meteorological drought analysis (Hayes *et al.*, 1999; Khan *et al.*, 2008; Gocic and Trajkovic, 2014).

Hydrological drought is expressed based on the inadequacy of surface or sub-surface water supply in terms of streamflow, reservoir storage and groundwater depths. A number of studies have analysed streamflow to better understand hydrologic droughts (Tallaksen and van Lanen, 2004; Nalbantis, 2008; Sharma and Panu, 2012; Tabari *et al.*, 2013). Agricultural drought is defined as a reduction in soil moisture due to a shortfall of precipitation coupled with high evaporation rates (Tallaksen and van Lanen, 2004). On the other hand, socio-economic drought is associated with failure of water resources to meet water demands, thus associating droughts with supply and demand shortfalls. Economic impacts include both direct effects, such as lost income from crop yield reduction and secondary effects such as reduced spending in rural communities (American Meteorological Society, 2004).

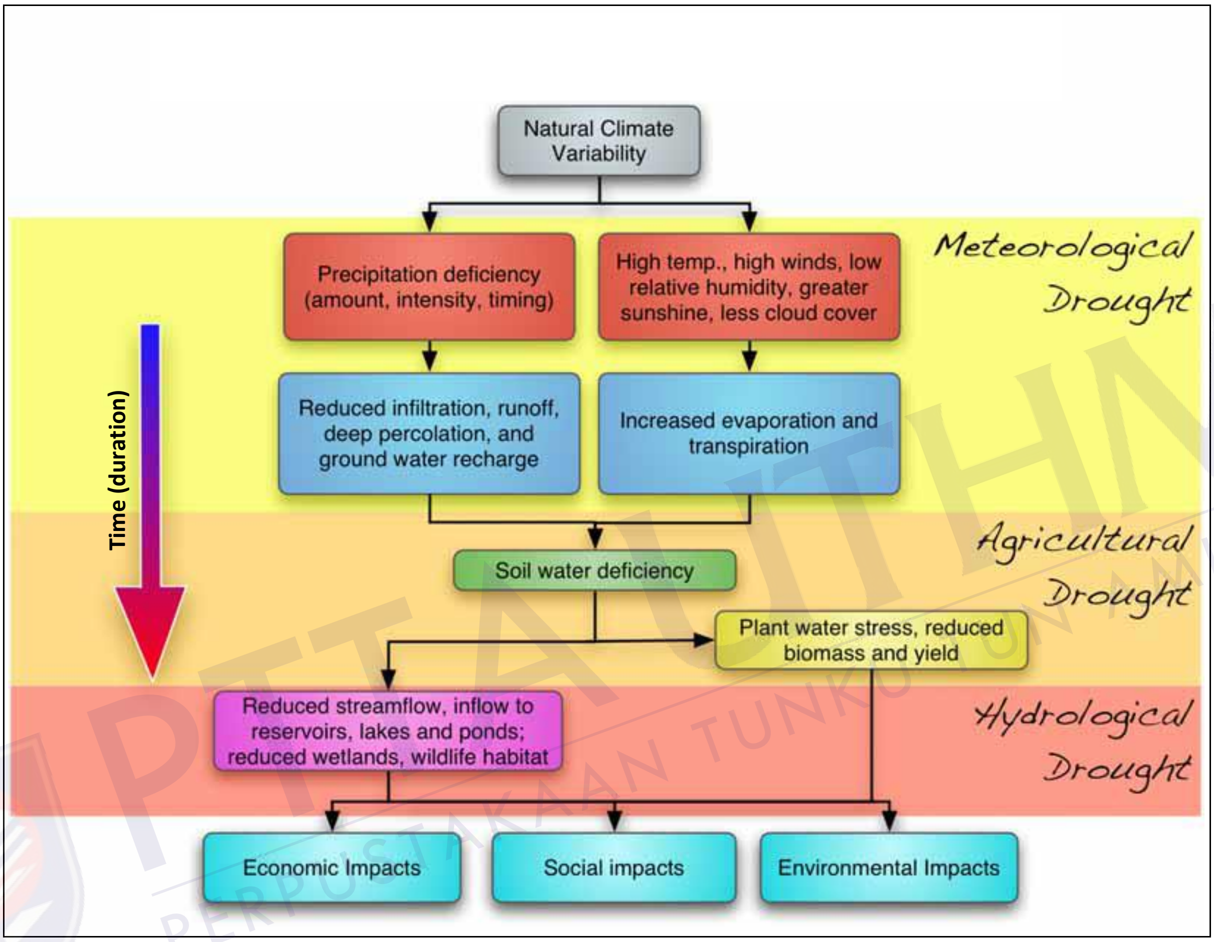

Figure 2.1 Sequence of drought occurrence (Source: National Drought Mitigation Center, University of Nebraska–Lincoln, USA; http://drought.unl.edu/DroughtBasics/TypesofDrought.aspx)

In contrast to meteorological droughts, the other three types of droughts occur less frequently because it usually takes weeks or months before precipitation deficiencies cause soil moisture deficiencies, declines in streamflow, reduced reservoir levels and lower groundwater tables. Therefore, for drought monitoring and early warning purposes, the meteorological drought indices provide the best initial assessment. Once the meteorological indices indicate the onset of a drought, other non-meteorological indices

REFERENCES

Agresti, A. (1990). *Categorical data analysis*. John Wiley & Sons, New York, USA.

Akhtari, R., Bandarabadi, S. R. and Saghafian, B. (2008). Spatio-temporal pattern of drought in Northeast of Iran. *International Conference on Drought management: Scientific and technological innovations*, Zaragoza,Spain. **80:** 71-77.

Alexander, L. V., Tapper, N., Zhang, X., Fowler, H. J., Tebaldi, C. and Lynch, A. (2009). "Climate extremes: progress and future directions." *International Journal of Climatology* **29**(3): 317-319.

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998) "Crop evapotranspiration: Guidelines for computing crop water requirements." *FAO Irrigation and Drainage Paper No. 56.* Online at: http://www.fao.org/docrep/X0490E/X0490E00.htm.

Alley, W. M. (1984). "The Palmer Drought Severity Index: Limitations and assumptions." *Journal of Climate and Applied Meteorology* **23**: 1100 - 1109.

American Meteorological Society, A. (2004). *Statement on meteorological drought*. *Bull. Am. Meteorol. Soc.* 85: 771-773.

Andrews, D. F. (1972). "Plots of High-Dimensional Data." *Biometrics* **28**(1): 125-136.

Angelidis, P., Maris, F., Kotsovinos, N. and Hrissanthou, V. (2012). "Computation of Drought Index SPI with Alternative Distribution Functions." *Water Resources Management* **26**(9): 2453-2473.

Araghinejad, S. (2011). "An Approach for Probabilistic Hydrological Drought Forecasting." *Water Resources Management* **25**(1): 191-200.

Asadi Zarch, M., Malekinezhad, H., Mobin, M., Dastorani, M. and Kousari, M. (2011). "Drought Monitoring by Reconnaissance Drought Index (RDI) in Iran." *Water Resources Management* **25**(13): 3485-3504.

Bacanli, U., Firat, M. and Dikbas, F. (2009). "Adaptive Neuro-Fuzzy Inference System for drought forecasting." *Stochastic Environmental Research and Risk Assessment* **23**(8): 1143-1154.

Barua, S., Muttil, N., Ng, A. W. M. and Perera, B. J. C. (2012). "Rainfall trend and its implications for water resource management within the Yarra River catchment, Australia." *Hydrological Processes* **27**(12): 1727-1738.

Barua, S., Ng, A. and Perera, B. (2011). "Comparative Evaluation of Drought Indexes: Case Study on the Yarra River Catchment in Australia." *Journal of Water Resources Planning and Management* **137**(2): 215-226.

Barua, S., Ng, A. W. M. and Perera, B. J. C. (2012). "Artificial Neural Network Based Drought Forecasting Using a Nonlinear Aggregated Drought Index." *Journal of Hydrologic Engineering* **17**(12): 1408-1413.

Barua, S., Perera, B. J. C., Ng, A. W. M. and Tran, D. (2010). "Drought forecasting using an aggregated drought index and artificial neural network." *Journal of Water and Climate Change* **1**(3): 193-206.

Behzadi, J. (2013). "An Evaluation of Two Drought Indices, Standard Distribution and Deciles in Guilan, Iran." *Greener Journal of Social Sciences* **3**(9): 472-478.

Ben-Zvi, A. (1987). "Indices of hydrological drought in Israel." *Journal of Hydrology* **92**(1–2): 179-191.

Beran, M. A. and Rodier, J. A. (1985). *Hydrological aspects of drought*. *In: UNESCO-WMO Studies and Reports in Hydrology 39*. Geneva. Presses Universitaires de France, Vendome.

Bonaccorso, B., Cancelliere, A. and Rossi, G. (2003). "An analytical formulation of return period of drought severity." *Stochastic Environmental Research and Risk Assessment* **17**(3): 157-174.

Boughton, W. and Chiew, F. (2008). Estimating runoff inungauged catchments from rainfall, PET and the AWBM model Griffith University, Brisbane, Australia.

Box, G. E. P., Jenkins, G. M. and Reinsel, G. C. (1994). *Time Series Analysis: Forecasting and Control*. Prentice Hall, Englewood Cliffs, NJ.

Bureau of Meteorology (BoM) (2003). "*Drought statement*. Available at: http://www.bom.gov.au/announcements/ (accessed May 2013).

Bureau of Meteorology (BoM) (2010). "*Rainfall Deciles*. http://www.bom.gov.au/climate/maps/ (accessed on 10 October 2011).

Bureau of Meteorology (BoM) (2011). "*Living with Drought*. http://www.bom.gov.au/climate/drought//livedrought.shtml (accessed November, 2011).

Bureau of Meteorology (BoM) (2012). "*Climate Data Online*. http://www.bom.gov.au/climate/data/ (accessed on 21 October 2013).

Burn, D. H. and Hag Elnur, M. A. (2002). "Detection of hydrologic trends and variability." *Journal of Hydrology* **255**(1–4): 107-122.

Cancelliere, A., Mauro, G., Bonaccorso, B. and Rossi, G. (2007). "Drought forecasting using the Standardized Precipitation Index." *Water Resources Management* **21**(5): 801-819.

Chakravarti, I. M., Laha, R. G. and Roy, J. (1967). *Handbook of Methods of Applied Statistics*. John Wiley and Sons, New York.

Changnon, S. A. and Changnon, J. M. (1992). "Temporal fluctuations in weather disasters: 1950–1989." *Climate Change* **22**: 191-208.

Chiew, F., Vaze, J., Viney, N., Jordan, P., Perraud, J.-M., Zhang, L., Teng, J., Young, W., Penaarancibia, J., Morden, R., Freebairn, A., Austin, J., Hill, P., Wiesenfeld, C. and Murphy, R. (2008). *Rainfall-runoff modelling across the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project.* CSIRO, Australia: 66.

Chow, V., Maidment, D. and Mays, L. (1988). *Applied Hydrology*. Mc Graw Hill Book Company, New York.

Chowdhury, R. K. and Beecham, S. (2010). "Australian rainfall trends and their relation to the southern oscillation index." *Hydrological Processes* **24**(4): 504-514.

Christopher, Z., M., N. O. and Lu, Z. (2002). *Regionalization of daily stream flow in Australia using wavelets and k-means analysis*. *CMA Research Report*. Centre for Mathematics and its Applications (CMA): MRR02 - 003, Australian National University, Canberra.

Clausen, B. and Pearson, C. P. (1995). "Regional frequency analysis of annual maximum streamflow drought." *Journal of Hydrology* **173**(1–4): 111-130.

Cox, D. R. and Lewis, P. A. W. (1996). *The Statistical Analysis of Series of Events*. John Wiley and Sons, London.

Croitoru, A.-E., Holobaca, I.-H., Lazar, C., Moldovan, F. and Imbroane, A. (2012). "Air temperature trend and the impact on winter wheat phenology in Romania." *Climatic Change* **111**(2): 393-410.

Dalezios, N. R., Loukas, A., Vasiliades, L. and Liakopoulos, E. (2001). "Severity-duration-frequency analysis of droughts and wet periods in Greece." *Hydrol. Sci. J.* **45**(5): 751-768.

Dogan, S., Berktay, A. and Singh, V. P. (2012). "Comparison of multi-monthly rainfall-based drought severity indices, with application to semi-arid Konya closed basin, Turkey." *Journal of Hydrology* **470–471**(0): 255-268.

Dracup, J. A., Lee, K. S. and Paulson, E. N. J. (1980). "On the statistical characteristics of drought events." *Water Resour Res* **16**(2): 289-296.

Drapela, K. and Drapelova, I. (2011). "Application of Mann-Kendall test and the Sen's slope estimates for trend detection in deposition data from Bílý Kříž (Beskydy Mts., the Czech Republic) 1997-2010." *Beskydy* **4**(2): 133-146.

Du, J., Fang, J., Xu, W. and Shi, P. (2012). "Analysis of dry/wet conditions using the standardized precipitation index and its potential usefulness for drought/flood monitoring in Hunan Province, China." *Stochastic Environmental Research and Risk Assessment*: 1-11.

Durdu, O. F. (2010). "Application of linear stochastic models for drought forecasting in the Büyük Menderes river basin, western Turkey." *Stochastic Environmental Research and Risk Assessment* **24**(8): 1145-1162.

Fawcett, R. (2004). A long-term trend in Melbourne rainfall? *Bulletin of the Australian Meteorological and Oceanographic Society* **17**: 122–126.

Fei Tian, Yonghui Yang, Shumin Han, Moiwo, J. P. and Qiu, G. (2010). "Determination of the period of major runoff decline and related driving factors in Ye River Basin, North China." *Journal of Water and Climate Change* **1**(2): 154-163.

Ganguli, P. and Reddy, M. J. (2014). "Evaluation of trends and multivariate frequency analysis of droughts in three meteorological subdivisions of western India." *International Journal of Climatology* **34**(3): 911-928.

Gao, Z. L., Fu, Y. L., Li, Y. H., Liu, J. X., Chen, N. and Zhang, X. P. (2012). "Trends of streamflow, sediment load and their dynamic relation for the catchments in the middle reaches of the Yellow River over the past five decades." *Hydrology and Earth System Sciences* **16**: 3219-3231.

Gato, S. (2012). Characterising low rainfall events in Greater Melbourne using Standard Precipitation Index. *In Proceedings of the 34th Hydrology and Water Resources Symposium*, Sydney, Australia.

Gergis, J., Gallant, A., Braganza, K., Karoly, D., Allen, K., Cullen, L., D'Arrigo, R., Goodwin, I., Grierson, P. and McGregor, S. (2012). "On the long-term context of the 1997–2009 'Big Dry' in South-Eastern Australia: insights from a 206-year multi-proxy rainfall reconstruction." *Climatic Change* **111**(3-4): 923-944.

Gibbs, W. J. (1984). "The great Australian drought: 1982–1983*." *Disasters* **8**(2): 89-104.

Gibbs, W. J. and Maher, J. V. (1967). *Rainfall deciles as drought indicators. Bureau of Meteorology Bulletin No 48*. Commonwealth of Australia, Melbourne.

Gocic, M. and Trajkovic, S. (2014). "Spatiotemporal characteristics of drought in Serbia." *Journal of Hydrology* **510**(0): 110-123.

Grebner, D. and Roesch, T. (1997). Regional dependence and application of DAD relationships. *Proceedings of FRIEND'97— Regional Hydrology: Concepts and Models for Sustainable Water Resource Management*, Postojna, Slovenia, International Association of Hydrological Sciences. IAHS Publication 246: 223-230.

Guerreiro, S. B., Kilsby, C. G. and Serinaldi, F. (2014). "Analysis of time variation of rainfall in transnational basins in Iberia: abrupt changes or trends?" *International Journal of Climatology* **34**(1): 114-133.

Guttman, N. B. (1998). "Comparing the Palmer Drought Index and the Standardized Precipitation Index." *Journal of the American Water Resources Association* **34**(1): 113-121.

Guttman, N. B. (1999). "ACCEPTING THE STANDARDIZED PRECIPITATION INDEX: A CALCULATION ALGORITHM1." *JAWRA Journal of the American Water Resources Association* **35**(2): 311-322.

Han, P., Wang, P. X., Zhang, S. Y. and Zhu, D. H. (2010). "Drought forecasting based on the remote sensing data using ARIMA models." *Mathematical and Computer Modelling* **51**(11–12): 1398-1403.

Hayes, M., M., S., N., W. and M., W. (2011). "The Lincoln Declaration on Drought Indices: Universal Meteorological Drought Index Recommended." *Bull. Amer. Meteor. Soc.* **92**: 485-488.

Hayes, M., Svoboda, M., Wilhite, D. and Vanyarkho, O. (1999). "Monitoring the 1996 drought using the SPI." *Bull Amer Meteor Soc 80*: 429-438.

Hayes, M. J. (2003). "*Drought indices*. http://www.drought.unl.edu/whatis/indices.htm (Accessed on 2 May 2011).

Heim Jr, R. R. (2002). "A review of twentieth-century drought indices used in the United States." *Bulletin of the American Meteorological Society* **83**(8): 1149-1165.

Helsel, D. R. and Hirsch, R. M. (2002). *Statistical Methods in Water Resources Techniques of Water Resources Investigations*. Book 4, Chapter A3. U.S. Geological Survey, Washington, DC.

Henriques, A. G. and Santos, M. J. J. (1999). "Regional drought distribution model." *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere* **24**(1–2): 19-22.

Intergovernmental Panel on Climate Change (IPCC) (2007). *Climate change 2007: Synthesis report*. Valencia, Spain.

Isaacson, D. L. and Madsen, R. (1976). *Markov Chains: Theory and Applications*. John Wiley, New York.

Janga Reddy, M. and Ganguli, P. (2012). "Application of copulas for derivation of drought severity–duration–frequency curves." *Hydrological Processes* **26**(11): 1672-1685.

Jiang, J. M. and You, X. T. (1996). "Where and when did an abrupt climate change occur in China during the last 43 years? ." *Theor. Appl. Climatol.* **55**: 33-39.

Jin, X., Xu, C.-y., Zhang, Q. and Chen, Y. D. (2009). "Regionalization study of a conceptual hydrological model in Dongjiang basin, south China." *Quaternary International* **208**(1–2): 129-137.

Kanellou, E., Domenikiotis, C., Blanta, A., Hondronikou, E. and Dalezios, N. R. (2008). "Index - based Drought Assessment in Semi-Arid Area of Greece based on Conventional Data." *European Water* **23/24**: 87/98.

Karavitis, C. A., Alexandris, S., Tsesmelis, D. E. and Athanasopoulos, G. (2011). "Application of the Standardized Precipitation Index (SPI) in Greece." *Water* **3**: 787-805.

Karl, T. R. and Knight, R. W. (1985). *Atlas of Monthly Palmer Hydrological Drought Indices (1931 - 1983) for the Contiguous United States Historical Climatology Series 3 - 7*. National Climatic data Center, Asheville, NC.

Karpouzos, D. K., Kavalieratou, S. and Babajimopoulos, C. (2010). "Trend Analysis of Precipitation Data in Pieria Region (Greece)." *European Water*(30): 31-40.

Keim, B. D. and Cruise, J. F. (1998). "A Technique to Measure Trends in the Frequency of Discrete Random Events." *Journal of Climate* **11**(5): 848-855.

Keyantash, J. and Dracup, J. A. (2002). "The quantification of drought: an evaluation of drought indices." *Bull Amer Meteor Soc* **83**(8).

Keyantash, J. A. and Dracup, J. A. (2004). "An aggregate drought index: Assessing drought severity based on fluctuations in the hydrologic cycle and surface water storage." *Water Resour. Res.* **40**(9): W09304.

Khalili, D., Farnoud, T., Jamshidi, H., Kamgar-Haghighi, A. and Zand-Parsa, S. (2011). "Comparability Analyses of the SPI and RDI Meteorological Drought Indices in Different Climatic Zones." *Water Resources Management* **25**(6): 1737-1757.

Khan, S., Gabriel, H. F. and Rana, T. (2008). "Standard precipitation index to track drought and assess impact of rainfall on watertables in irrigation areas." *Irrigation and Drainage Systems* **22**(2): 159-177.

Khastagir, A. (2013). Risk and severity of bushfires and the impact of fire on water supply reliability in Victoria, Australia, RMIT University.

Khattree, R. and Naik, D. N. (2002). "Andrews plots for multivariate data: some new suggestions and applications." *Journal of Statistical Planning and Inference* **100**(2): 411-425.

Kiem, A. S. and Verdon-Kidd, D. C. (2010). "Towards understanding hydroclimatic change in Victoria, Australia - preliminary insights into the "Big Dry"." *Hydrol. Earth Syst. Sci.* **14**: 433-445.

Kim, C. J., Park, M. J. and Lee, J. H. (2014). "Analysis of climate change impacts on the spatial and frequency patterns of drought using a potential drought hazard mapping approach." *International Journal of Climatology* **34**(1): 61-80.

Kim, S., Kim, B., Ahn, T. J. and Kim, H. S. (2011). "Spatio-temporal characterization of Korean drought using severity–area–duration curve analysis." *Water and Environment Journal* **25**(1): 22-30.

Kinninmonth, W. R., Voice, M. E., Beard, G. S., de Hoedt, G. C. and Mullen, C. E. (2000). Australian climate services for drought management. In: Wilhite (ed.). *Drought: A Global Assessment*. Routledge, London **Volume 1:** 210-222.

Kizza, M., Guerrero, J.-L., Rodhe, A., Xu, C. and Ntale, H. K. (2012). "Modelling catchment inflows into Lake Victoria: Regionalisation of the parameters of a conceptual water balance model." *Hydrology Research* **44**(5): 789-808.

Kokkonen, T. S., Jakeman, A. J., Young, P. C. and Koivusalo, H. J. (2003). "Predicting daily flows in ungauged catchments: model regionalization from catchment descriptors at the Coweeta Hydrologic Laboratory, North Carolina." *Hydrological Processes* **17**(11): 2219-2238.

Kovacs, J., Kovacs, S., Magyar, N., Tanos, P., Hatvani, I. G. and Anda, A. (2014). "Classification into homogeneous groups using combined cluster and discriminant analysis." *Environmental Modelling & Software* **57**(0): 52-59.

Kundzewicz, Z. and Robson, A. (2004). "Change detection in hydrological records - a review of the methodology." *Hydrological Sciences Journal* **49**: 7-19.

Laaha, G. and Bloschl, G. (2006). "A comparison of low flow regionalisation methods—catchment grouping." *Journal of Hydrology* **323**(1–4): 193-214.

Lana, X., Serra, C. and Burgueño, A. (2001). "Patterns of monthly rainfall shortage and excess in terms of the standardized precipitation index for Catalonia (NE Spain)." *International Journal of Climatology* **21**(13): 1669-1691.

Lloyd-Hughes, B. (2012). "A spatio-temporal structure-based approach to drought characterisation." *International Journal of Climatology* **32**(3): 406-418.

Lloyd-Hughes, B. and Saunders, M. A. (2002). "A drought climatology for Europe." *International Journal of Climatology* **22**(13): 1571-1592.

Loch, A., Wheeler, S., Bjornlund, H., Beecham, S., Edwards, J., Zuo, A. and Shanahan, M. (2013). *The role of water markets in climate change adaptation*. Gold Coast: National Climate Change Adaptation Research Facility: 142.

Lohani, V. K. and Loganathan, G. V. (1997). "An early warning system for drought management using the Palmer Drought Index." *Journal of the American Water Resources Association* **33**(6): 1375-1386.

Lohani, V. K., Loganathan, G. V. and Mostaghim, S. (1998). "Long-Term Analysis and Short-Term Forecasting of Dry Spells by Palmer Drought Severity Index." *Nordic Hydrology* **29**(1): 21-40.

Loukas, A. and Vasiliades, L. (2004). "Probabilistic analysis of drought spatiotemporal characteristics in Thessaly region, Greece." *Natural Hazards and Earth System Sciences* **4**: 719-731.

Lyra, G. B., Oliveira-Júnior, J. F. and Zeri, M. (2014). "Cluster analysis applied to the spatial and temporal variability of monthly rainfall in Alagoas state, Northeast of Brazil." *International Journal of Climatology*.

McKee, T. B., Doesken, N. J. and Kleist, J. (1993). The relationship of drought frequency and duration to time scales. *In: Proc. 8th Conf. on Applied Climatol, 17-22 January, Americ Meteorol Soc, Mass*. 179-184.

Meehl, G. A., Boer, G. J., Covey, C., Latif, M. and Stouffer, R. J. (2000). "The Coupled Model Intercomparison Project (CMIP)." *Bulletin of the American Meteorological Society* **81**(2): 313-318.

Melbourne Water (2010). "*Drought Management*. http://melbournewater.com.au/content/news_and_events/whats_new/whats_new/20100929.asp (Assessed 21 May 2013).

Mendicino, G., Senatore, A. and Versace, P. (2008). "A Groundwater Resource Index (GRI) for drought monitoring and forecasting in a mediterranean climate." *Journal of Hydrology* **357**(3–4): 282-302.

Merz, R. and Bloschl, G. (2004). "Regionalisation of catchment model parameters." *Journal of Hydrology* **287**(1–4): 95-123.

Mishra, A., Singh, V. and Desai, V. (2009). "Drought characterization: a probabilistic approach." *Stochastic Environmental Research and Risk Assessment* **23**(1): 41-55.

Mishra, A. K. and Desai, V. R. (2005). "Drought forecasting using stochastic models." *Stochastic Environmental Research and Risk Assessment* **19**(5): 326-339.

Mishra, A. K. and Desai, V. R. (2005). "Spatial and temporal drought analysis in the Kansabati river basin, India." *International Journal of River Basin Management* **3**(1): 31-41.

Mishra, A. K. and Desai, V. R. (2006). "Drought forecasting using feed-forward recursive neural network." *Ecological Modelling* **198**(1–2): 127-138.

Mishra, A. K. and Singh, V. P. (2009). "Analysis of drought severity-area-frequency curves using a general circulation model and scenario uncertainty." *J. Geophys. Res.* **114**(D6): D06120.

Mishra, A. K. and Singh, V. P. (2010). "A review of drought concepts." *Journal of Hydrology* **391**(1-2): 202-216.

Mishra, A. K. and Singh, V. P. (2011). "Drought modeling - A review." *Journal of Hydrology* **403**(1-2): 157-175.

Moreira, E. E., Coelho, C. A., Paulo, A. A., Pereira, L. S. and Mexia, J. T. (2008). "SPI-based drought category prediction using loglinear models." *Journal of Hydrology* **354**(1–4): 116-130.

Morid, S., Smakhtin, V. and Moghaddasi, M. (2006). "Comparison of seven meteorological indices for drought monitoring in Iran." *International Journal of Climatology* **26**(7): 971-985.

Mpelasoka, F., Hennessy, K., Jones, R. and Bates, B. (2008). "Comparison of suitable drought indices for climate change impacts assessment over Australia towards resource management." *International Journal of Climatology* **28**(10): 1283-1292.

Mu, X., Li, Y., Gao, P., Shao, H. and Wang, F. (2012). "The Runoff Declining Process and Water Quality in Songhuajiang River Catchment, China under Global Climatic Change." *CLEAN – Soil, Air, Water* **40**(4): 394-401.

Murphy, B. F. and Timbal, B. (2008). "A review of recent climate variability and climate change in southeastern Australia." *International Journal of Climatology* **28**(7): 859-879.

Nalbantis, I. (2008). "Evaluation of a hydrological drought index." *European Water* **23**(24): 67-77.

Nalbantis, I. and Tsakiris, G. (2009). "Assessment of Hydrological Drought Revisited." *Water Resources Management* **23**(5): 881-897.

Nathan, R. J. and McMahon, T. A. (1990). "Identification of homogeneous regions for the purposes of regionalisation." *Journal of Hydrology* **121**(1–4): 217-238.

National Climate Centre (2010). "*Australia's wettest September on record but it is not enough to clear long-term rainfall deficits*. http://www.bom.gov.au/climate/current/special-statements.shtml (Accessesd May 2012).

Nazahiyah, R., Jayasuriya, N. and Bhuiyan, M. (2013). *The Challenges of Drought Monitoring and Early Warning*. In Proceedings of People and the Planet 2013 Conference: Transforming the Future, RMIT University, Melbourne, Australia.

Nazahiyah, R., Jayasuriya, N. and Bhuiyan, M. A. (2012). Trend analysis of drought using Standardised Precipitation Index (SPI) in Victoria, Australia. *In Proceedings of the 34th Hydrology and Water Resources Symposium*, Sydney, Australia. 441-448.

Nazahiyah, R., Jayasuriya, N. and Bhuiyan, M. A. (2014). "Assessing droughts using meteorological drought indices in Victoria, Australia." *Journal of Hydrology Research*.

Nicholls, N., Drosdowsky, W. and Lavery, B. (1997). "Australian rainfall variability and change." *Weather* **52**(3): 66-72.

Nikbakht, J., Tabari, H. and Talaee, P. H. (2013). "Streamflow drought severity analysis by percent of normal index (PNI) in northwest Iran." *Theoretical and Applied Climatology* **112**(3-4): 565-573.

Ochola, W. O. and Kerkides, P. (2003). "A Markov chain simulation model for predicting critical wet and dry spells in Kenya: analysing rainfall events in the Kano Plains." *Irrigation and Drainage* **52**(4): 327-342.

Palmer, W. C. (1965). *Meteorological Drought*. *Research Paper No. 45.* U.S. Department of Commerce Weather Bureau, Washington, D.C.

Panu, U. S. and Sharma, T. C. (2002). "Challenges in drought research: some perspectives and future directions." *Hydrological Sciences Journal* **47**(sup1): S19-S30.

Parajka, J., Merz, R. and Blöschl, G. (2005). "A comparison of regionalisation methods for catchment model parameters." *Hydrol. Earth Syst. Sci.* **9**(3): 157-171.

Partal, T. and Kahya, E. (2006). "Trend analysis in Turkish precipitation data." *Hydrological Processes* **20**(9): 2011-2026.

Pashiardis, S. and Michaelides, S. (2008). "Implementation of the Standardized Precipitation Index (SPI) and the Reconnaissance Drought Index (RDI) for Regional Drought Assessment: A case study for Cyprus." *European Water* **23/24**: 57-65.

Paulo, A. and Pereira, L. (2007). "Prediction of SPI Drought Class Transitions Using Markov Chains." *Water Resources Management* **21**(10): 1813-1827.

Paulo, A. and Pereira, L. (2008). "Stochastic Prediction of Drought Class Transitions." *Water Resources Management* **22**(9): 1277-1296.

Paulo, A. A., Ferreira, E., Coelho, C. and Pereira, L. S. (2005). "Drought class transition analysis through Markov and Loglinear models, an approach to early warning." *Agricultural Water Management* **77**(1-3): 59-81.

Paulo, A. A. and Pereira, L. S. (2006). "Drought Concepts and Characterization." *Water International* **31**(1): 37-49.

Paulo, A. A., Rosa, R. D. and Pereira, L. S. (2012). "Climate trends and behaviour of drought indices based on precipitation and evapotranspiration in Portugal." *Nat. Hazards Earth Syst. Sci.* **12**: 1481-1491.

Peel, M. C. and Bloschl, G. (2011). "Hydrological modelling in a changing world." *Progress in Physical Geography* **35**: 249.

Pilgrim, D. H. (1987). *Australian rainfall and runoff: A guide to flood estimation*. The Institution of Engineers, Australia Barton, ACT.

Potter, N. J., Chiew, F. H. S. and Frost, A. J. (2010). "An assessment of the severity of recent reductions in rainfall and runoff in the Murray–Darling Basin." *Journal of Hydrology* **381**(1–2): 52-64.

Ragno, G., Luca, M. D. and Ioele, G. (2007). "An application of cluster analysis and multivariate classification methods to spring water monitoring data." *Microchemical Journal* **87**(2): 119-127.

Raziei, T., Bordi, I. and Pereira, L. S. (2008). "A precipitation-based regionalization for Western Iran and regional drought variability." *Hydrol. Earth Syst. Sci.* **12**(6): 1309-1321.

Raziei, T., Saghafian, B., Paulo, A., Pereira, L. and Bordi, I. (2009). "Spatial Patterns and Temporal Variability of Drought in Western Iran." *Water Resources Management* **23**(3): 439-455.

Rohli, R. V. and Keim, B. D. (1994). "Spatial and temporal characteristics of extreme-high-summer-temperature events in the South-Central United States." *Physical Geography* **15**(4): 310-324.

Rossi, G., Benedini, M., Tsakiris, G. and Giakoumakis, S. (1992). "On regional drought estimation and analysis." *Water Resources Management* **6**(4): 249-277.

Saghafian, B., Shokoohi, A. and Raziei, T. (2003). Drought spatial analysis and development of severity-duration-frequency curves for an arid region. *Proceedings of International Conference on Hydrology of the Mediterranean and Semiarid Regions*, Montpellier. **278:** 305-311.

Santos, J., Portela, M. and Pulido-Calvo, I. (2011). "Regional Frequency Analysis of Droughts in Portugal." *Water Resources Management* **25**(14): 3537-3558.

Seibert, J. (1999). "Regionalisation of parameters for a conceptual rainfall-runoff model." *Agricultural and Forest Meteorology* **98–99**(0): 279-293.

Sen, P. K. (1968). "Estimates of the Regression Coefficient Based on Kendall's Tau." *Journal of the American Statistical Association* **63**(324): 1379-1389.

Shadmani, M., Marofi, S. and Roknian, M. (2012). "Trend Analysis in Reference Evapotranspiration Using Mann-Kendall and Spearman's Rho Tests in Arid Regions of Iran." *Water Resources Management* **26**(1): 211-224.

Shafer, B. A. and Dezman, L. E. (1982). Development of a Surface Water Supply Index (SWSI) to assess the severity of drought conditions in snowpack runoff areas. *In Proceedings of the 50th Annual Western Snow Conference*, Reno, Nevada. 164 - 175.

Sharma, T. and Panu, U. (2012). "Modeling drought durations using Markov chains: a case study of streamflow droughts in Canadian prairies." *Hydrol Sci J* **57**(4): 1-18.

Shiau, J. T. and Modarres, R. (2009). "Copula-based drought severity-duration-frequency analysis in Iran." *Meteorological Applications* **16**(4): 481-489.

Sirdas, S. and Sen, Z. (2003). "Spatio-temporal drought analysis in the Trakya region, Turkey." *Hydrological Sciences Journal* **48**(5): 809-820.

Smadi, M. and Zghoul, A. (2006). "A sudden change in rainfall characteristics in Amman, Jordan during the mid 1950s." *Am J Environ Sci* **2**(3): 84-99.

Smith, I. (2004). An assessment of recent trends in Australian rainfall. *Australian Meteorological Magazine* **53**: 163–173.

Sneyers, R. (1990). *On the Statistical Analysis of Series of Observations*. World Meteorological Organization, Geneva, Switzerland: Technical Note no. 143.

Soltani, S., Saboohi, R. and Yaghmaei, L. (2012). "Rainfall and rainy days trend in Iran." *Climatic Change* **110**(1-2): 187-213.

Sonali, P. and Nagesh Kumar, D. (2013). "Review of trend detection methods and their application to detect temperature changes in India." *Journal of Hydrology* **476**(0): 212-227.

Sonmez, F. K., KoMuScu, A., Erkan, A. and Turgu, E. (2005). "An Analysis of Spatial and Temporal Dimension of Drought Vulnerability in Turkey Using the Standardized Precipitation Index." *Natural Hazards* **35**(2): 243-264.

Srikanthan, R. and McMahon, T. A. (1981). "Log Pearson III distribution — An empirically-derived plotting position." *Journal of Hydrology* **52**(1–2): 161-163.

Srikanthan, R. and McMahon, T. A. (1985). "Recurrence interval of drought events through stochastic analysis of rainfall and streamflow data " *Hydrological Sciences* **30**(2): 197-206.

Stephens, M. A. (1974). "EDF Statistics for Goodness of Fit and Some Comparisons." *Journal of the American Statistical Association* **69**: 730-737.

Stern, H., Moodie, N., Cornall-Reilly, J., Forster, T. and McBride, P. (2004). *Long-term Trend in Melbourne Rainfall, in Climate and Water*. Abstracts from the 16th Australian New Zealand Climate Forum, 8-10 November.

Subash, N. and Ram Mohan, H. S. (2011). "Trend detection in rainfall and evaluation of standardized precipitation index as a drought assessment index for rice–wheat productivity over IGR in India." *International Journal of Climatology* **31**(11): 1694-1709.

Suppiah, R. and Hennessy, K. (1996). Trends in the intensity and frequency of heavy rainfall in tropical Australia and links with the southern oscillation. *Australian Meteorological Magazine* **45**: 1-17.

Suppiah, R., Hennessy, K., Whetton, P., K., M., Macadam, I., Bathols, J., Ricketts, J. and Page, C. (2007). Australian climate change projections derived from simulations performed for the IPCC 4th Assessment Report. *Australian Meteorological Magazine* **56**: 131–152.

Suppiah, R., Whetton, P. H. and Watterson, I. G. (2004). *Climate Change In Victoria*. *Assessment of climate change for Victoria: 2001-2002* Climate Impact Group, CSIRO Atmospheric Research: 33.

Tabari, H., Abghari, H. and Hosseinzadeh Talaee, P. (2012). "Temporal trends and spatial characteristics of drought and rainfall in arid and semiarid regions of Iran." *Hydrological Processes* **26**(22): 3351-3361.

Tabari, H., Marofi, S., Aeini, A., Talaee, P. H. and Mohammadi, K. (2011). "Trend analysis of reference evapotranspiration in the western half of Iran." *Agricultural and Forest Meteorology* **151**(2): 128-136.

Tabari, H., Nikbakht, J. and Talaee, P. H. (2013). "Hydrological Drought Assessment in Northwestern Iran Based on Streamflow Drought Index (SDI)." *Water Resources Management* **27**(1): 137-151.

Tallaksen, L. M., Madsen, H. and Clausen, B. (1997). "On the definition and modelling of streamflow drought duration and deficit volume." *Hydrological Sciences Journal* **42**(1): 15-33.

Tallaksen, L. M., Madsen, H. and Hisdal, H. (2004). *Frequency analysis*. L. M. In: Tallaksen, Van Lanen, H.A.J. (Eds.). *Hydrological drought - Processes and estimation methods for streamflow and groundwater.* Elsevier, Amsterdam.

Tallaksen, L. M. and van Lanen, H. A. J. e. (2004). *Hydrological drought - Processes and Estimation Methods for Streamflow and Groundwater. Developments in Water Sciences 48.* Elsevier B. V., The Netherlands

Tan, K. S. and Rhodes, B. G. (2008). Implications of the 1997-2006 Drought on Water Resources Planning for Melbourne. *In Proceedings of Water Down Under 2008*. Engineers Australia; Causal Productions: 2016-2027.

Thornthwaite, C. W. (1948). "An Approach toward a Rational Classification of Climate." *Geographical Review* **38**(1): 55-94.

Tigkas, D. (2008). "Drought Characterisation and Monitoring in Regions of Greece." *European Water* **23/24**: 29-39.

Todisco, F., Mannocchi, F. and Vergni, L. (2013). "Severity–duration–frequency curves in the mitigation of drought impact: an agricultural case study." *Natural Hazards* **65**(3): 1863-1881.

Tsakiris, G., Pangalou, D. and Vangelis, H. (2007). "Regional Drought Assessment Based on the Reconnaissance Drought Index (RDI)." *Water Resources Management* **21**(5): 821-833.

Tsakiris, G., Tigkas, D., Vangelis, H. and Pangalou, D. (2007). Regional Drought Identification and Assessment. Case Study in Crete. In: Rossi et al (ed.). *Methods and Tools for Drought Analysis and Management*. Springer, Netherlands**:** 169-191.

Tsakiris, G. and Vangelis, H. (2004). "Towards a Drought Watch System based on Spatial SPI." *Water Resources Management* **18**(1): 1-12.

Tsakiris, G. and Vangelis, H. (2005). "Establishing a Drought Index Incorporating Evapotranspiration." *Europian Water* **9/10**: 3-11.

Turkes, M. and Tatlı, H. (2009). "Use of the standardized precipitation index (SPI) and a modified SPI for shaping the drought probabilities over Turkey." *International Journal of Climatology* **29**(15): 2270-2282.

Ummenhofer, C. C., England, M. H., McIntosh, P. C., Meyers, G. A., Pook, M. J., Risbey, J. S., Gupta, A. S. and Taschetto, A. S. (2009). "What causes southeast Australia's worst droughts?" *Geophysical Research Letters* **36**(4): L04706.

Varol, M. and Sen, B. (2009). "Assessment of surface water quality using multivariate statistical techniques: a case study of Behrimaz Stream, Turkey." *Environmental Monitoring and Assessment* **159**(1): 543-553.

Verdon-Kidd, C., D. and Kiem, A. S. (2010). "Quantifying Drought Risk in a Nonstationary Climate." *J. Hydrometeor* **11**: 1019-1031.

Verdon-Kidd, D. C. and Kiem, A. S. (2009). Nature and causes of protracted droughts in Southeast Australia - Comparison between the Federation, WWII and Big Dry droughts. Geophys. Res. Lett. **36**.

Vezza, P., Comoglio, C., Rosso, M. and Viglione, A. (2010). "Low Flows Regionalization in North-Western Italy." *Water Resources Management* **24**(14): 4049-4074.

Vicente-Serrano, S. (2006). "Differences in Spatial Patterns of Drought on Different Time Scales: An Analysis of the Iberian Peninsula." *Water Resources Management* **20**(1): 37-60.

Webb, C. P. (2010). *Bureau of Meteorology Reference Evapotranspiration Calculations*. Climate Services Centre, Queensland Regional Office, Bureau of Meteorology: 20.

Weglarczyk, S. (2009). "On the stationarity of extreme levels of some Polish lakes. I. Preliminary results from statistical test." *Limnological Review* **9**(2-3): 129-138.

Wilhite, D. (2005). Drought Policy and Preparedness: The Australian Experience in an International Context. L. Botterill and D. Wilhite. *From Disaster Response to Risk Management*. Springer Netherlands, **22:** 157-176.

Wilhite, D. A. and Glantz, M. H. (1985). "Understanding the drought phenomenon: the role of definitions." *Water International* **10**(3): 111-120.

WMO (1988). *Analyzing Long Time Series of Hydrological Data with Respect to Climate Variability*. *WCAP-3, WMO/TD-No: 224*. Geneva, Switzerland: 1-12.

Wu, H., Svoboda, M. D., Hayes, M. J., Wilhite, D. A. and Wen, F. (2007). "Appropriate application of the standardized precipitation index in arid locations and dry seasons." *International Journal of Climatology* **27**(1): 65-79.

Xiaofan, L., Liliang, R., Fei, Y. and Bang, Y. (2009). Meteorological Drought Forecasting Using Markov Chain Model. *International Conference on Environmental Science and Information Application Technology*. **2:** 23-26.

Yang, Y. and Tian, F. (2009). "Abrupt change of runoff and its major driving factors in Haihe River Catchment, China." *Journal of Hydrology* **374**(3–4): 373-383.

Yenigun, K., Gumus, V. and Bulut, H. (2008). Trends in streamflow of the Euphrates basin, Turkey. *Proceedings of the Institution of Civil Engineers - Water Management*. **161:** 189-198.

Yevjevich, V. (1967). "An Objective Approach to Definitions and Investigations of Continental Hydrologic Drought." *Hydrology Paper Nr. 23. Fort Collins, CO: Colorado State University*.

Young, K. (1992). *A three-way model for interpolating monthly precipitation values*. *Monthly Weather Review*. 120: 2561-2569.

Yu, B. and Neil, T. D. (1993). "Long-term variations in regional rainfall in the south-west of Western Australia and the difference between average and high intensity rainfalls." *International Journal of Climatology* **13**: 77-88.

Yue, S., Pilon, P. and Cavadias, G. (2002). "Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series." *Journal of Hydrology* **259**(1–4): 254-271.

Yusof, F., Hui-Mean, F., Suhaila, J. and Yusof, Z. (2013). "Characterisation of Drought Properties with Bivariate Copula Analysis." *Water Resources Management*: 1-25.

Yusof, F., Hui-Mean, F., Suhaila, J., Yusop, Z. and Ching-Yee, K. (2014). "Rainfall characterisation by application of standardised precipitation index (SPI) in Peninsular Malaysia." *Theoretical and Applied Climatology* **115**(3-4): 503-516.

Zamani, R., Tabari, H. and Willems, P. (2014). "Extreme streamflow drought in the Karkheh river basin (Iran): probabilistic and regional analyses." *Natural Hazards*: 1-20.

Zang, C. and Liu, J. (2013). "Trend analysis for the flows of green and blue water in the Heihe River basin, northwestern China." *Journal of Hydrology* **502**(0): 27-36.

Zelenhasic, E. and Salvai, A. (1987). "A method of streamflow drought analysis." *Water Resources Research* **23**(1): 156-168.

Zhang, Q., Xu, C.-y., Becker, S. and Jiang, T. (2006). "Sediment and runoff changes in the Yangtze River basin during past 50 years." *Journal of Hydrology* **331**(3–4): 511-523.

Zhang, Y., Guo, F., Meng, W. and Wang, X.-Q. (2009). "Water quality assessment and source identification of Daliao river basin using multivariate statistical methods." *Environmental Monitoring and Assessment* **152**(1): 105-121.

Zhao, J., Fu, G., Lei, K. and Li, Y. (2011). "Multivariate analysis of surface water quality in the Three Gorges area of China and implications for water management." *Journal of Environmental Sciences* **23**(9): 1460-1471.